

Heartwood, sapwood and bark content of teak trees grown in Karnataka, India

Vindhya Prasad Tewari • K.M. Mariswamy

Received: 2012-05-14;

Accepted: 2012-08-24

© Northeast Forestry University and Springer-Verlag Berlin Heidelberg 2013

Abstract: We evaluated heartwood, sapwood and bark content in teak trees. A total of 27 sample plots were laid out in teak plantations raised by State Forest Department in Karnataka covering different age groups (11–36 years), density (516–2061 trees/ha) and sites. From these plantations, a total of 130 trees were felled for estimating the yield and bark content in relation to diameter at breast height (DBH), age and density. Bark content ranged from 22.2%–54.3%. Heartwood and sapwood content were analyzed by sampling five trees each from two different plantations, one 30 years old at 553 trees·ha⁻¹ and the other 32 years old at 911 trees·ha⁻¹. The highest heartwood proportion of stem wood volume (over-bark) was 56.3% and the lowest was 37.1%. The sapwood proportion ranged from 12.9%–23.0%, while the bark content ranged from 27.8%–43.5%. The heartwood proportion increased with DBH, while the proportion of bark decreased. The sapwood proportion did not vary with DBH. The bark content decreased with increasing age, but increased with stand density. There was no significant difference in heartwood content with respect to age or stand density because the ages of the two stands were similar. A larger dataset from young to mature stands is needed to describe the relationships between age and stand density and heartwood, sapwood and bark content of trees.

Keywords: diameter at breast height (DBH); age; stand density; heartwood; sapwood; bark; teak; India

Introduction

The properties and versatility of teak (*Tectona grandis* L. f.), and its suitability for an array of uses is well documented. The potential for growing and managing teak in different ecological zones

and under different situations is being increasingly recognized, leading to intensive domestication and cultivation of the species in countries/regions beyond its natural habitat (Perez and Kaninen 2003). Teak has been grown under plantation conditions for 150 years.

Teak occurs naturally in parts of India, Myanmar, Laos and Thailand. It has been naturalized in Java, where it was introduced about 400–600 years ago (Kadambi 1972; White 1991). Early introductions of teak outside Asia were made in Nigeria, with the first plantations being of Indian origin in 1902 and subsequently of Burmese origin (Horne 1966). The first pure teak plantation in tropical America was perhaps established in Trinidad in 1913 with seeds from Burma. Teak planting in Honduras, Panama, and Costa Rica started between 1927 and 1929 (Ball et al. 2000).

Teak is the world's most widely cultivated high-grade tropical heartwood, covering approximately 6.0 million ha worldwide (Bhat and Ma 2004). Of this global distribution, about 94% lies in tropical Asia, with India (44%) and Indonesia (31%) contributing the bulk of the resource. Other countries, including Thailand, Myanmar, Bangladesh and Sri Lanka, contribute significantly with 17% in total. About 4.5% of the teak plantations are in tropical Africa and the rest are in tropical America, mostly in Costa Rica and Trinidad and Tobago (Pandey 1998).

Teak is one of the most important tropical timber species and is suitable for multiple end-uses, including construction, furniture and cabinets, railway sleeper cars, decorative veneer, joinery, ship and vehicle body building, mining and reconstituted products. The quality of teak timber, which could be improved by intensive management, depends partly on tree form and partly on basic wood structure and strength properties. The major structural factors that should receive attention are, among others: stem size, bole shape, knot size and frequency, and heartwood-sapwood proportions (Bhat 2000).

When living parenchyma cells in the outer, functional sapwood begin to die, the substances they contain are used as energy to fuel the production of phenols and quinines, which protect the tree from pathogen and insect attack (Datta and Kumar 1987). Heartwood is defined as the inner layers of the wood, which, in the growing tree, have ceased to contain living cells, and in

The online version is available at <http://www.springerlink.com>

Vindhya Prasad Tewari (✉) • K.M. Mariswamy
Institute of Wood Science and Technology, 18th Cross, Malleswaram,
Bangalore 560003, India
E-mail: vptewari@yahoo.com

Corresponding editor: Yu Lei

which the reserve materials (starches) have been removed or converted into heartwood. The amount of heartwood varies considerably with age, site and growth rate, and between trees within the same stand at the same age. This implies a strong influence of cell age, growth of the individual tree and a strong genetic heritability (Hillis 1987). Most mature trees contain a central core of heartwood usually darker in color than the surrounding sapwood, which often darkens considerably when the cut surface is exposed to air. The transformation from sapwood usually occurs abruptly over a few rows of cells (Hillis 1987).

A high proportion of heartwood is one of the most desired wood characteristics for plantation-grown teak (Tewari 1999; Bailleres and Durang 2000). Several studies report the heartwood content by stem height, age, stand density, and climatic conditions for teak in different countries (Nair and Chavan 1985; Bhat 1995; Brennan and Radomiljac 1998; Trockenbrodt and Josue 1998; Priya and Bhat 1999; Bhat et al. 2001; Perez and Kanninen 2003). Bhat (1998) showed that increase in the growth rate did not retard the formation of heartwood. However, the amount of heartwood in teak is related to tree age (Okuyama et al. 2000) and silvicultural practices (Morataya et al. 1999).

The ratio of cross-sectional area of heartwood to DBH has been reported to increase with age (up to 80%–90%) at ages greater than 30 years on plantation-grown teak in different regions of the world (Bhat 1995; Kokutze et al. 2004). Little importance has been attributed to the proportion of heartwood in many countries where teak forests are older than 50 years because the cross-sectional area of older trees (over 40 years) is over 90% heartwood. Lately, the need to produce fast growing teak timber within rotations of 20–30 years increased the importance of producing high heartwood content, which is considered a primary factor during visual assessment and wood valuation. In timber with clearly demarcated sapwood and heartwood, those trees with higher percentages of heartwood will yield more saleable timber; conversely, a high proportion of sapwood is not a problem in treated poles because it is easily penetrated by preservatives and thereafter may be more resistant to pests and fungal infections than the heartwood itself (Oteng-Amoako 2004).

High-yield forest plantations are becoming an important source of wood in the tropics and increasing the plantation pro-

ductivity is a primary task. The selection of tree species for large-scale afforestation and reforestation programmes should not be only based on tree growth and survival. The quality and utilisation potential of timber should also be taken into consideration. The aim of our study was to evaluate the heartwood, sapwood and bark content in teak trees in Karnataka, India.

Materials and methods

Our data were collected from teak plantations in Karnataka raised by the State Forest Department on forest lands. The annual rainfall in these areas varies from 1,600–4,500 mm. The mean annual minimum and maximum temperatures are 11°C and 38 °C, respectively. Twenty-seven sample plots were laid out in plantations of different ages (11–36 years) and tree densities (516 to 2,061 trees·ha⁻¹) at sites in Haliyal, Yellapur, Koppa, Virajpet and Madikeri forest divisions, and representing different geographic and rainfall conditions. All trees inside the 27 plots were measured for diameter at breast height (DBH) and grouped into diameter classes. Five trees representing these diameter classes were felled in each plot. In total, 130 trees were harvested for estimation of volume (over-bark and under-bark) and bark content. The length of the felled tree was measured with a tape and stump height was added to get the total height. For the computation of total tree volume, the stem with a minimum diameter outside bark of 5 cm was considered. The volume was then calculated by dividing the stem into logs of 3 m length, measuring the mid-diameters and applying Huber's formula ($V=ML$; V =total volume in m³, M =cross sectional area at mid length of log in m² and L =log length in m) to estimate individual log volumes. For estimating under-bark volume, the bark thickness at DBH was measured with a bark gauge on one side which was multiplied by 2 and subtracted from the DBH (over-bark) to arrive at the value of DBH (under-bark). Similarly, bark thickness at the mid point of each log was also determined with the bark gauge. The bark volume was estimated by subtracting the volume (under-bark) from the volume (over-bark). The summary statistics are given in Table 1.

Table 1. Summary statistics for 130 trees used for estimation of bark content

Variable	DBH (cm)	Height (m)	Age (years)	Density (trees·ha ⁻¹)	Volume over-bark (m ³)	Volume under-bark (m ³)	Bark volume (m ³)
Minimum	5.5	6.5	11	516	0.0063	0.00348	0.00282
Maximum	36	21.4	36	2061	1.10367	0.75576	0.3529
Mean	17.24	14.47	28.26	992.74	0.20702	0.13512	0.07361
Std. Dev.	5.95	3.48	5.52	376.74	0.17995	0.12479	0.05717

For estimation of heartwood and sapwood content, 10 trees were sampled from two plantations located at different locations (five trees from each site), the details of which are provided in Table 2.

The trees were cut at breast height and diameters (over-bark and under-bark) and diameter of heartwood were measured (taken as the average of two cross-sectional measurements). Tree

volume (over-bark and under-bark) and heartwood volume were estimated using the geometric cylinder volume equation, in combination with a stem form factor of 0.48, which is widely used for teak in Karnataka and other regions. Sapwood volume was estimated by subtracting the heartwood volume from the volume (inside bark) (Table 3). Non-linear regression analyses were used to determine the relationship of heartwood and sapwood to DBH

and bark content by tree age, DBH and density.

Table 2. General data of the two sites for heartwood and sapwood estimation

Location	Age (year)	Stand density (trees·ha ⁻¹)	Mean minimum temperature (°C)	Mean maximum temperature (°C)	Annual rainfall (mm)	Elevation (m)	DBH range (cm)	Height range (m)
Balehonnur, Koppa	30	553	22	31	2032	714	9.85–23.05	9.7–14.8
Dandeli, Haliyal	32	911	15	36	2887	472	8.05–22.4	8.8–17.2

Table 3. Summary statistics for heartwood, sapwood and bark content of teak trees harvested from two sites in Karnataka

Variable	DBH (cm)	Height (m)	Volume over-bark (m ³)	Heartwood volume (m ³)	Sapwood volume (m ³)	Bark volume (m ³)	Heartwood volume (%)	Sapwood volume (%)	Bark volume (%)
Minimum	8.1	6.3	0.02149	0.00796	0.00418	0.00935	37.05	12.95	27.77
Maximum	23.1	17.2	0.31195	0.1669	0.06128	0.08964	56.33	23.04	43.52
Mean	14.88	12.13	0.13553	0.06807	0.02458	0.04287	46.35	18.37	35.28
Std. Dev.	5.25	4.26	0.10906	0.06057	0.01995	0.02977	5.77	3.25	5.77

Results and discussion

For the first dataset consisting of 130 trees, the bark content ranged from 22.2%–54.3%. Perez and Kanninen (2003), in studies of teak plantations in Costa Rica, found that the bark represented 14%–37% of the total volume. The relationship of total wood volume (over-bark and under-bark) and bark volume to DBH is shown in Fig. 1, and indicated that the wood and bark volume increased with increasing DBH.

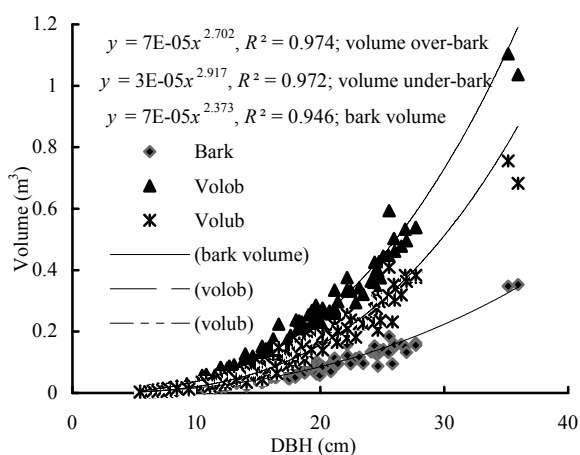


Fig. 1 Relationship of wood and bark volume to DBH of teak in Karnataka

The volume (under-bark) and bark proportion of total wood volume (over-bark) by age, density and DBH are presented in Fig. 2. Proportion of wood volume increased with age and DBH but decreased with stand density. The bark proportion decreased polynomially with age and DBH but increased with density. A better fit was observed with DBH than with stand density and age. Equations predicting bark volume (%) from age and density presented poor goodness of fit ($R^2 < 0.40$).

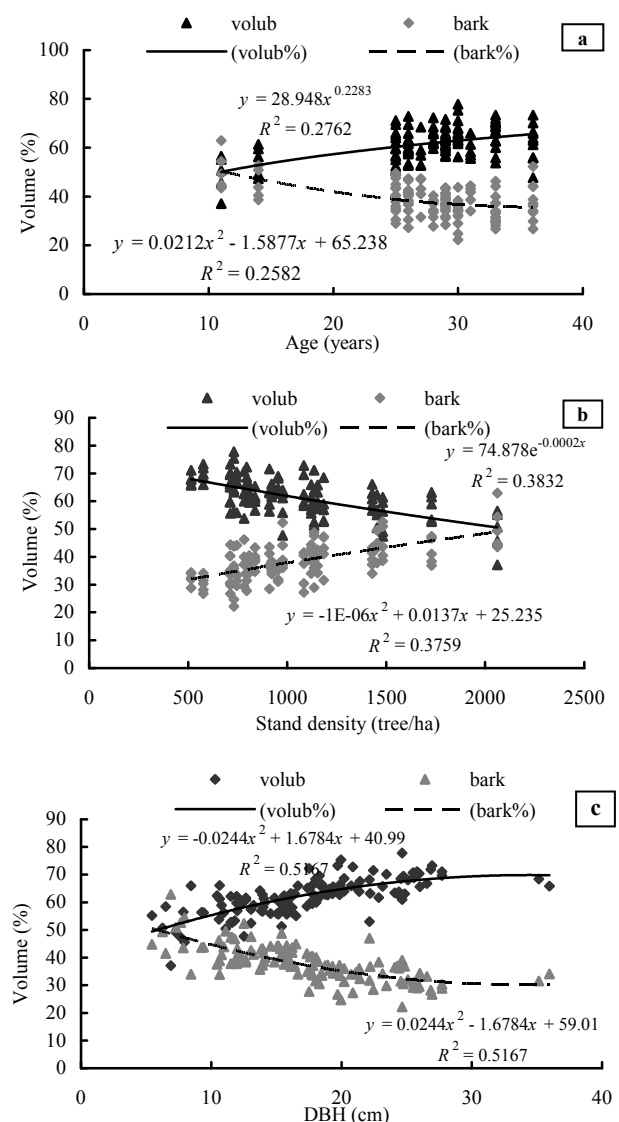


Fig. 2 Proportion of under-bark volume and bark proportion of total tree volume by (a) age, (b) stand density and (c) DBH

In the second dataset of 10 trees harvested for estimating heartwood, sapwood and bark content, the highest heartwood proportion of total tree volume was 56.33% while the lowest was 37.05% (average 46.35%). The proportion of sapwood ranged from 12.95% to 23.04% (average 18.37%), and bark volume ranged from 27.77% to 43.52% (Table 3) with an average of 38.28%. The heartwood proportion was marginally higher in the 32 year old plantation (47%) than in the 30 year old plantation (45.8%). Similarly, bark content was 36.1% and 34.3%, respectively, in 30- and 32-year-old plantations while sapwood content was similar (18.1% and 18.7%).

Tree total volume and sapwood volume showed power growth ($V=ax^b$) by DBH, while heartwood and bark volume increased polynomially (Fig. 3a). Models representing relationships between total, heartwood, sapwood and bark volume to DBH showed an excellent fit with very high R^2 (Fig. 3a), indicating that 94%–99% of the variation in the data was explained by the models. Heartwood proportion increased with increasing DBH, while the proportion of bark decreased (Fig. 3b). On the other hand, sapwood showed no significant correlation with DBH.

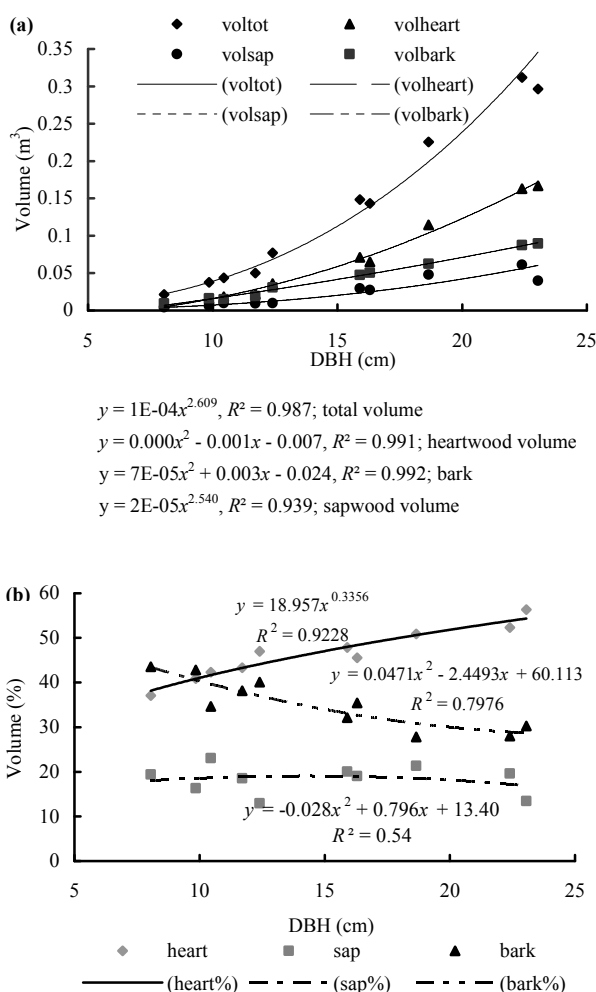


Fig. 3 (a) Relationship of total, heartwood, sapwood and bark volume to DBH and (b) Variation of heartwood, bark and sapwood proportion of total volume by DBH.

Teak is a relatively fast growing species and, therefore, rotations for stands under intensive management can be 20–30 years. The present study indicated that teak contains heartwood up to 56% of the total volume at 30–32 years and this proportion increases according to $Y=aX^b$ with increasing DBH. Costa Rica teak trees yielded a heartwood proportion of 55% of the total volume at 30 years, increasing logarithmically with increasing age and, consequently, with DBH (Perez and Kanninen 2003). Arce (2001) found heartwood proportions of 33%–37% in 10-year-old teak grown in a dry region of Costa Rica. Heartwood volume in a tree increases exponentially with increasing DBH. The physiological explanation is that as sapwood must be continually laid down concurrently with growth of the crown, its proportion can only be maintained at an optimum by formation of heartwood and this act as a regulatory mechanism to control the amount of sapwood (Bamber 1976).

Conclusion

Heartwood volume increases with increasing DBH in teak plantations in Karnataka. Also, bark content decreases with increasing age and DBH, but increases with stand density. Difference in heartwood proportion with age and stand density in two plantations was only marginal and not significant since the plantations were of similar age. Hence a larger dataset from young to mature stands is required to arrive at a clear conclusion.

Acknowledgements

The authors wish to thank the Director, IWST for providing all necessary facilities for this study. The help rendered by Dr. A.N. Arun Kumar, Scientist-E and Sh. N. Chandrashekar, RA-I in field data collection is highly appreciated. The authors are also thankful to the officials of Karnataka State Forest Department for granting permission to conduct the study in their plantations and also for extending help and support during the field work.

References

- Arce VH. 2001. Relación albura-duramen y características físicas de la madera de teca (*Tectona grandis*) en plantaciones de diez años con dos diferentes densidades de plantación en Playa Garza, Guanacaste. Heredia, Costa Rica: Tesis de grado, Universidad Nacional, p. 36.
- Bailleres H, Durang P. 2000. Non-destructive techniques for wood quality assessments of plantation-grown teak. *Bois et Forest des Tropiques*, **263**(1): 17–28.
- Ball JB, Pandey D, Hirai S. 2000. Global overview of teak plantations. In: *Proceedings of the Regional Seminar on 'Site, Technology and Productivity of teak plantations'*. Chiang Mai, Thailand, 26–29 January 1999. pp. 11–34.
- Bamber RK. 1976. Heartwood, its function and formation. *Wood Science and Technology*, **10**(1): 1–8.
- Bhat KM. 1995. A note on heartwood proportion and wood density of 8-year-old teak. *The Indian Forester*, **121**(6): 514–516.
- Bhat KM. 1998. Properties of fast-grown teakwood: Impact on end-user's

- requirements. *Journal of Tropical Forest Products*, **4**(1): 1–10.
- Bhat KM. 2000. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. *Bois et Forêts des Tropiques*, **263**(1): 6–15.
- Bhat KM, Priya PB, Rugmini P. 2001. Characterization of juvenile wood in teak. *Wood Science and Technology*, **34**(6): 517–532.
- Bhat KM, Hwan Ok Ma. 2004. Teak growers unite. *ITTO Tropical Forest Update*, **14**(1): 3–5.
- Brennan GK, Radomiljac AM. 1998. Preliminary observations on the utilization and wood properties of plantation teak (*Tectona grandis*) and African mahogany (*Khaya senegalensis*) grown near Kununurra, Western Australia. *Australian Forestry*, **61**(2): 120–126.
- Datta SK, Kumar A. 1987. Histochemical studies of the transition from sapwood to heartwood in *Tectona grandis*. *IAWQ Bulletin*, **8**(4): 363–368.
- Hillis WE. 1987. *Heartwood and tree exudates*. Berlin: Springer Verlag, p. 281.
- Horne JEM. 1966. Teak in Nigeria. Nigerian Forestry Information Bulletin (New Series) No. 16, p. 38.
- Kadambi K. 1972. *Silviculture and management of teak*. Texas: Bulletin 24, School of Forestry, Stephen F. Austin State University, p. 25.
- Kokutze AD, Bailleres H, Stokes A, Kokou K. 2004. Proportion and quality of heartwood in Tongolese teak. *Forest Ecology and Management*, **189**: 37–48.
- Morataya R, Galloway G, Berninger F, Kanninen M. 1999. Foliage biomass-sapwood (area and volume) relationships of *Tectona grandis* L.F. and *Gmelina arborea* Roxb.: silvicultural implications. *Forest Ecology and Management*, **113**: 231–239.
- Nair MNB, Chavan RR. 1885. Dimensional analysis of some wood parameters in eleven timber trees. *The Indian Forester*, **111**(6): 410–417.
- Okuyama T, Yamamoto H, Wahyudi I, Hadi YS, Bhat KM. 2000. Growth stresses and some wood quality attributes in planted teak. In: Proceedings of the IUFRO Congress, Kuala Lumpur, Malaysia, p. 154.
- Oteng-Amoako AA. 2004. Making the grade. *ITTO Tropical Forest Update*, **14**(1): 6–7.
- Pandey D. 1998. Forest plantation areas, 1995. Report of the FAO project GCP/INT/628/UK, p. 94.
- Perez LD, Kanninen M. 2003. Heartwood, sapwood and bark content, and wood dry density of young and mature teak (*Tectona grandis*) trees grown in Costa Rica. *Silva Fennica*, **37**(1): 45–54.
- Priya PB, Bhat KM. 1999. Influence of rainfall, irrigation and age on the growth periodicity and wood structure in teak (*Tectona grandis*). *IAWA Journal*, **20**(2): 181–192.
- Tewari DN. 1999. *A monograph on teak (Tectona grandis)*. Dehra Dun, India: International Book Distributors, p. 235.
- Trockenbrodt M, Josue J. 1998. Wood properties and utilization potential of plantation teak (*Tectona grandis*) in Malaysia – A critical review. *Journal of Tropical Forest Products*, **5**(1): 58–70.
- White KJ. 1991. Teak-some aspects of research and development. Publication 1991/17. Bangkok, Thailand, FAO, p. 44.